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PASSIVE TESTING AT LOS ALAMOS*

by

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ABSTRACT

The testing program directed toward the evaluation of passive solar heating concepts is described. The Los Alamos Scientific Laboratory is monitoring 15 passive solar heated buildings, all in the private sector, and all but one in northern New Mexico. The purpose is to evaluate a wide variety of passive solar heating concepts under similar conditions. The buildings are described, but few results are yet available. Results from passive solar heated test rooms at Los Alamos are presented. Of a total of 14 test rooms, data are presented for nine, for both a sunny day and a cloudy day. These include two water walls; five Trombe walls, one vented and the others unvented, one plain; two with night insulation, Beadwall and night shade; and one with multiple glazings; two direct gain rooms, one plain and one with a three-layer roll-down shade; and an air convective loop. The characteristics of the rooms are described and tentative conclusions are drawn from some of the data.

The Los Alamos Scientific Laboratory is conducting a test program on passive solar heated buildings. This is part of a larger evaluation effort which has the overall objective of developing a quantitative basis for design.

The LASL passive program consists of two major elements: the acquisition of data from actual occupied passive solar heated buildings, and the testing of specific passive solar heated elements in test rooms at Los Alamos. A major purpose of both programs is to provide quantitative data against which to test the validity of mathematical simulation techniques used to predict the performance of these systems. A previous paper[1] provides an example of the comparison taken for two passive test rooms during a period of January 1977. Data taken on a Trombe wall and a water wall test room were shown to be in excellent agreement with a mathematical model based on a thermal network analysis approach.

MONITORING OF PASSIVE BUILDINGS

LASL has instrumented 15 different passive solar heated buildings and has obtained data from each. All but one of these buildings is in nortnern New Mexico, the exception being the Doug Kelbaugh house in Princeton, New Jersey. The buildings represent a wide variety of passive solar heating approaches.

Installed instrumentation consists of thermocouples to measure temperature, a pyranometer to measure solar radiation, and an anemometer and wind vane to measure wind velocity and direction. Two types of data acquisition systems have been used. In the original installations, data were recorded on a 16-channel chart recorder. The recorder was controlled by a pair of timers which resulted in a data point plotted once each hour for each of the 16 channels. The points are digitized by hand for a few selected periods. Data were taken in this manner on seven buildings during the winter of

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1976-77. Although the method is cumbersome, the information obtained proved to be very revealing and worthwhile.

Beginning in December of 1977, nine 40-channel digital data acquisition systems were installed. This allowed for automatic processing of data with intermediate storage on tape cassette and subsequent playback.

Examples of data taken by the 16-point chart recorder are presented in a paper by Doug Kelbaugh in these proceedings. Examples of data taken by the digital data acquisition system are given in a paper by Balcomb entitled, "State of the Art" and another paper by Bruce Hunn entitled, "A Hybrid Passive/Active Solar House: First Year Performance of the Hunn Residence." Although voluminous data have been taken and plotted, detailed evaluation is a long process which has just begun. Some of the conclusions reached to date are presented in the three papers mentioned.

LASL TEST ROOMS

The LASL test rooms are small 40 sq ft frame structures where passive solar heating elements can be tested under carefully controlled conditions. To date, the test rooms have been operated without any auxiliary heating, that is in a "free running" mode.

The entire 10 ft x 5 ft south-side of each test room is glazed to provide for solar collection. (Exceptions are a small thermosiphon air heater test and two roof aperture, roof pond tests which have yet to be installed.) Except as noted, the glazing is two sheets of 1/8 in. Plexiglas. (Plexiglas is used instead of glass as a safety precaution.) The construction of the test rooms is 2 x 4 frame with fiberglass batts in the cavities and with one inch of foam insulation on the inside. The construction was chosen to minimize the thermal mass effect of the building structure in order to provide least confusion in interpreting the results of the passive elements. For convenience, the test rooms are built in adjacent pairs as shown in the plan view of Fig. 1. The overall thermal conductance of the test room, not including the south facade or the common wall, is 11.5 BTU/hr/°F or 0.23 BTU/hr/°F per square foot of south glazing. Due to the large ratio of glazed area to thermal load, the rooms are very strongly solar heated in the mid-winter months, generally running 50 to 70°F above the average outside ambient temperature.

The test room behavior is not intended to be strictly representative of the expected behavior of passive solar homes or buildings. An occupied building would generally be operated with an auxiliary heat source to maintain a minimum temperature and winter ventilation to prevent overheating. The principal purpose of the test rooms is to provide comparative data between two different approaches under identical operating conditions and also to provide data which can be used to validate the mathematical simulation models for the various passive approaches.

Care should be taken in direct comparisons of the resulting data presented. Normalizing of the physical variations shown in Table I must be completed before a true detailed comparison can be made.

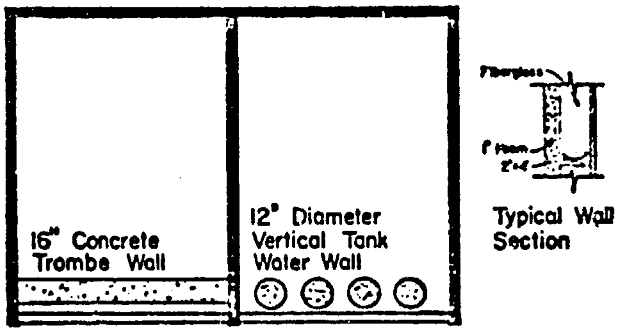


Fig. 1. Plan view of Passive Test Rooms.

INSTRUMENTATION AND DATA ACQUISITION

Temperatures in the test rooms are measured with chromel/alumel thermocouples connected through a reference junction to a Hewlett-Packard data acquisition calculator. The results are stored on cassette tape and subsequently transferred to mass storage in the LASL central computing facility. Weather data taken at the same site include horizontal, 45°, and vertical-south solar radiation measurements made with Eppley PSP, 8-48, and pΣ photovoltaic pyranometers, wind direction and velocity, and wet bulb temperature.

Of the 14 test rooms which have been built, 8 have been used to test thermal storage walls, two to test direct gain, two to test convective loops, and two will be used to test roof ponds under south roof apertures.

TEST ROOM RESULTS

Data taken on a water wall and a Trombe wall, both vented and unvented, have been published in a previous paper.[1] Data have been taken continuously through 1977 and up to the present time. During this interval many of the cells were being completed and instrumentation installed. Thus the most complete information is that obtained recently.

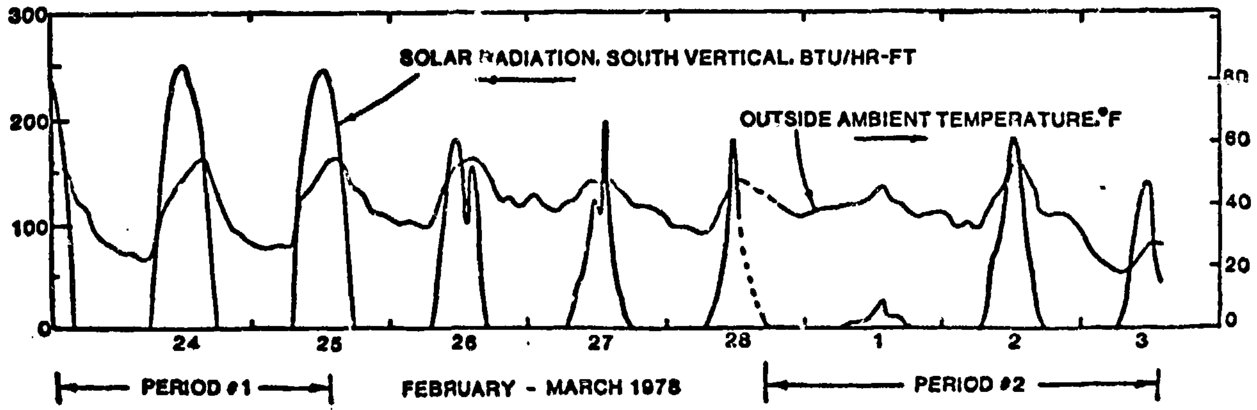
A particularly interesting test period occurred during late February and early March. The solar radiation and temperature data for this period are

TABLE 1

LASL TEST ROOM CHARACTERISTICS

Configuration	Solar Aperture, ft2	Mass Surface Exposed to Sun, ft2	Mass Surface Exposed to Room, ft2	Mass, lb	Heat Capacity, BTU/°F	Glazings No.	Glazings Type	Glazings Spacing
Water Wall, 19" tubes	45.4	41.4	43.0	3310	3310	2	1/8" Plex.	1"
Water Wall, 12" tubes	46.4	29.6	30.9	1500	1500	2	"	1"
Trombe Wall, vented	47.0	37.5	38.8	6400	1280	2	"	1"
Solid Wall	40.9	37.8	42.1	6950	1400	2	1/4" Plex.	3-1/2"
Solid Wall, with Beadwall	40.9	37.8	42.1	6950	1400	2	"	3-1/2"
Solid Wall, with Night Shade	45.9	39.4	42.1	6950	1400	2	1/8" Plex.	1"
Solid Wall, Multiple Glazings	36.4	35.0	42.1	6950	1400	1 4	1/8" Plex. .001 Tedlar	1" 1"
Thermocrete Wall	46.1	44.7	46.3	1570	--	2	1/8" Plex.	1"
Direct Gain	45.7	45.7	143.0	8500	1700	2	"	1"
Direct Gain, Insealshaid	45.8	39.8	139.6	8300	1680	2	1/8" Plex.	1"
Convective Loop	45.0	45.0	--	2500	2500	2	1/8" Plex.	1"

Fig. 4 LASL WEATHER



shown in Fig. 2. Out of this period, two separate time intervals have been chosen for presentation. The interval labeled "Period 1" is toward the end of a sequence of sunny days during which the data repeat in a periodic diurnal fashion. The interval marked "Period 2" is toward the end of a sequence of mixed weather. There was snow all day March 1. By studying these two intervals it is possible to compare test rooms under both clear-day and cloudy-day conditions. On subsequent data plots, the two time periods are shown plotted adjacent, deleting the three-day interval inbetween. Comparative data are shown in Figs. 3 through 11, with the conclusions and comments described in the figure captions. The case of a 16 in. solid concrete wall (unvented Trombe wall) is shown on each figure for comparison. This room has good performance and has the least temperature swing of all of the rooms tested. The plots show globe temperature measured in the center of the room. Specific characteristics of the rooms are given in Table 1.

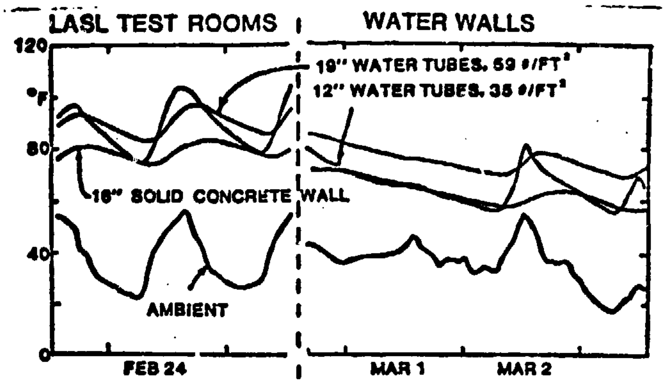


Fig. 3. Water Walls. The room with 19 in. water tubes has the highest average temperature of all the test rooms, although the swing is somewhat greater than that of the solid wall. The water is contained in three vertical cylindrical fiberglass tubes 9.3 ft high with a total noon-time subtended collection area of 41.4 sq ft. The 2 in. spaces between each tube and between the tubes and the side wall are blocked with 2 in. styrofoam pieces caulked around the edges.

The total subtended frontal area of the four 12 in. water tubes is 29.6 sq ft. After February 23 the styrofoam blocks were removed from the 12 in. water tube room. As had been noted during the previous winter tests, the swing in the water wall room is greater than that in the unvented Trombe wall,[1] and the minimum nighttime temperatures are comparable for the two cases for comparable thermal storage. The performance increase associated with the larger water mass in the 19 in. tubes is pronounced.

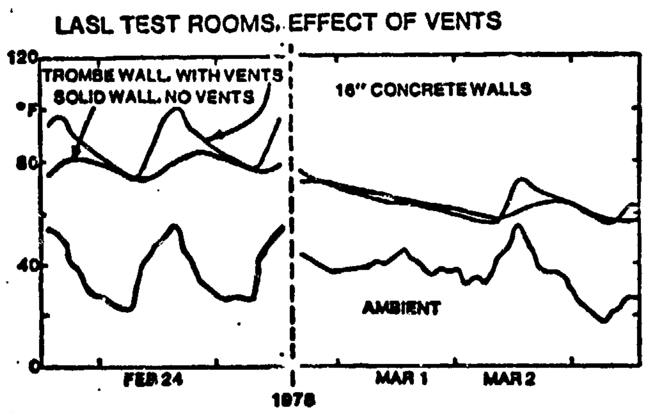


Fig. 4. Effect of Vents. Two nearly identical Trombe walls operated with and without thermocirculation vents show a dramatic difference. The effect of the thermocirculation is to heat the air in the room quickly during the morning. Thus the temperature swing is much greater than in the room without the vents. Thermocirculation is useful if the room needs heat during the day, otherwise it tends to overheat the room. If the room had more mass, to effectively store some of this extra heat, then the vents would be useful. They are also useful for a situation of low solar heating fraction where excess heat during the day can be fully utilized. In a strongly solar heated, lightweight frame structure such as the test rooms, the vents seem to be a disadvantage since they tend to increase the temperature swing without increasing the minimum nighttime temperatures.

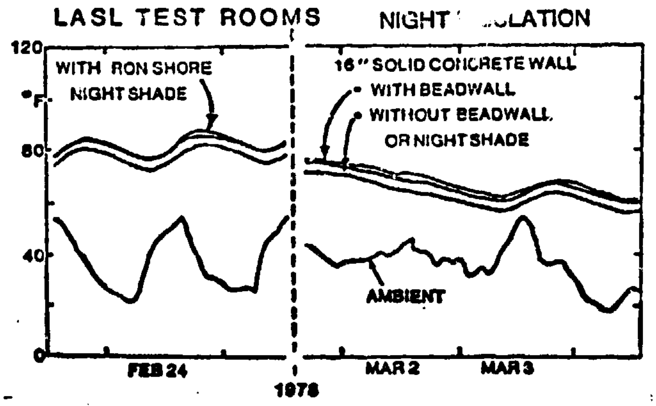


Fig. 5. Night Insulation. Insulating the glazing at night is expected to have a large beneficial effect in cold climates. During the test periods shown here, the nighttime temperatures were not severely low and thus the effect of the night insulation is not especially pronounced. Two types of night insulation were employed. The insulation was put in place at 5:00 p.m. each evening and removed at 8:00 a.m. the following morning. Two night insulation schemes were tested, both proprietary products. A pair of "Beadwalls" were purchased from the Zomeworks Corp. and installed by David Harrison. In these Beadwalls, styrofoam pellets fill the 3-1/2 in. space between the two glazing sheets at night and are removed during the day. An automatic system for doing this, utilizing a vacuum cleaner motor and associated valves and controls, came as part of the Beadwall package. It has operated very satisfactorily. In one of the Beadwall rooms, the space was left opened at all times during the test period; this room is the reference room, labeled 16 in. solid wall on each plot. Of all of the test rooms, these two are the most nearly identical except that one is operated with Beadwall and the other without. It is interesting to note that during an earlier test period in late September, with the Beadwall operated in a summer mode (that is, with the wall closed in the day and open at night), the Beadwall room operated 25°F cooler than the room without the Beadwall, showing a larger differential benefit in summer than in winter.

A second night insulation system is a roll-down night shade made of four layers of reflective cloth. The night shade is described in a separate paper by Ron Shore in these proceedings. It is designed with small vents on the bottom and will automatically inflate when lowered to provide a space between each layer. A U-track on each side provides an edge seal. The bottom of the shade rests against the floor to provide a bottom seal. The performance of the night shade seems comparable to the Beadwall during sunny weather but is slightly inferior during the extended cloudy period. The measured IR emittance of the outer layer is 0.373 and for the inside layers it is 0.073.

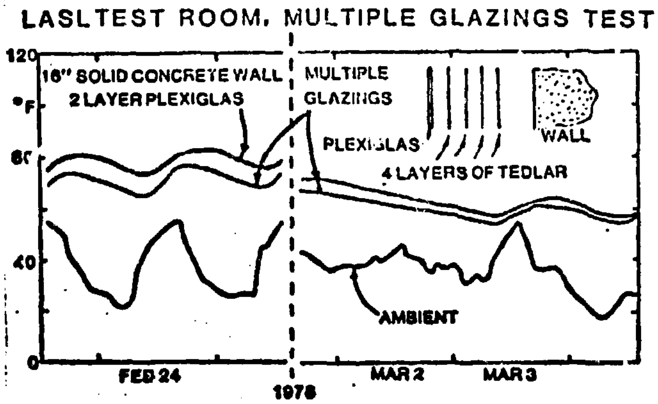


Fig. 6. Multiple Glazings. In one unvented 16" Trombe wall test room the rear sheet of Plexiglas was replaced with four layers of Tedlar. The Tedlar has a solar transmissivity of 94%. The lower performance of this test room as compared to the reference room is attributed primarily to the high infrared transmissivity of the Tedlar, as compared to Plexiglas or glass. A major part of the heat flow is by infrared radiation and this is less effectively interrupted by the four layers of Tedlar than by a single layer of Plexiglas. This disadvantage is apparently not balanced by the reduction in convection due to the many layers. Unfortunately, this comparison is clouded by the fact that the aperture of the Tedlar room is somewhat smaller than that of the reference room. In order to install the Tedlar, a 4 in. stripe around the perimeter was masked and therefore not effective solar collection area. This difference is noted in Table 1.

Future plans call for testing of "solar membrane," a proprietary product manufactured by Suntek Corporation. The advantage of the solar membrane is a low infrared transmittance with a solar transmittance greater than that of Tedlar.

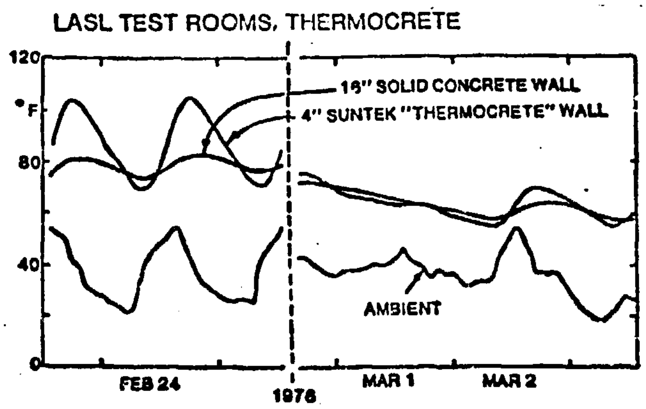


Fig. 7. Phase-Change Wall. A thermal storage wall of phase-change material was constructed from blocks manufactured by Suntek Corporation. This material is called "Thermocrete" and is being developed at the present time. The blocks used in the test room were purchased by LASL for this purpose. The blocks measured 8 in. by 16 in. by 4 in. and are made of a porous, low-density concrete coated on the outside with epoxy to make them water tight. The pores in the concrete are filled with a phase-change solution by evacuation of the block through a hole, inhalation of the solution through the hole, and then sealing off the hole. Considerable difficulty has been experienced with leaks in the blocks. (The data shown were taken prior to much leakage.) The blocks were stacked to make a 4 in. thick wall and the cracks between them sealed. The theoretical latent heat of fusion of these blocks should make them equivalent to a 24 in. concrete wall in thermal capacity. The best blocks manufactured by Suntek have demonstrated this thermal capacity in their tests. However due to difficulties in quality control, the blocks shipped to Los Alamos have about half this heat capacity, according to tests done at Suntek.[2]

The phase-change material used is a salt hydrate, calcium chloride hexahydrate ($CaCl.6H_2O$) which has a melting point of $\sim$ 80°F. However, the effect of encapsulating the salt hydrate in the porous concrete is to smear the phase-change over a temperature band of about 15°F.[2] This should explain why a plateau is not observed in the temperature profile each time the value swings through 80°F. Temperatures measured within the wall also show no temperature plateau.

These data indicate that a higher heat capacity should be obtained in order to benefit effectively from a phase-change material, either by using a thicker wall or by obtaining a much higher heat capacity within the 4 in. wall.

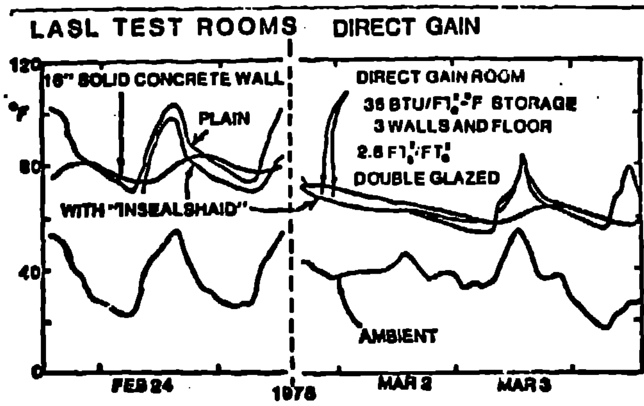


Fig. 8. Direct Gain. Data taken on two direct-gain test rooms are compared with the solid 16 in. concrete wall. In each of the direct-gain rooms the floor, the two side walls, and the back walls are covered with solid concrete blocks stacked to form a wall 5-1/2 in. thick. The side and back walls were not stacked to the roof line but to a height which would assure that all of the direct gain sun entering the room would shine on a concrete surface. The mass is 22% greater than that of the thermal storage wall room. The exposed concrete surface is 3.1 times greater than the solar aperture of the room. The color of the concrete blocks was left natural cement. The measured solar absorptance and IR emittance values are 0.75 and 0.90, respectively. The globe temperature measurements made in the rooms are at a height so that the globe is not directly lit by the sun.

Temperatures measured on the surface of the concrete and at the rear surface of the concrete indicate a 2.0 hour time lag between the direct heating of the surface and the arrival of that heat at the back face. Data taken in the side walls and floor show no surprises; the temperatures peak strongly for those surfaces which are in the direct sun at the time of their illumination and show much less pronounced heating at other times. Interpreting these results is somewhat clouded by the fact that the room temperature swing is so large.

Generalizing from data taken in a direct-gain room is extremely difficult. The thermal storage wall rooms are relatively easy to interpret because the situation is essentially one-dimensional. One would expect to see a difference between a room that is relatively shallow in the north-south direction (as are the test rooms) and a room of the same volume and having the same surface area and thermal load elongated in the north-south direction. Thus the data taken on the direct-gain rooms are not so universely applicable as data taken on the thermal storage wall rooms.

The curve marked direct-gain is a plain, double-glazed direct-gain situation.

"Insealshaid" is a special proprietary product made and marketed by the Ark-Tic-Seal Systems, Inc. It was purchased by LASL especially to fit the large 5 x 10 ft opening. It consists of three layers of flexible material mounted in an aluminum frame so that the layers can be easily rolled from the bottom up to the top. The purpose of the shade is to provide the room occupant a degree of control over the lighting level and the heat loss of the room. In the LASL tests the shade was used with two layers of material, a clear layer of Mylar, and a nearly opaque layer of Mylar permanently covering the opening. The device is fixed with small openings on the bottom and top so that the solar heat absorbed in the second layer will be thermally convected into the room. Dampers at the bottom and top close automatically to prevent reverse thermocirculation at night. The third layer has an infrared reflective coating on the inside surface. During these tests this layer was operated twice each day in order to cover the window during the night and be open during the day. The times of opening and closing were the same as for the Beadwall, at 8:00 a.m. and 5:00 p.m. During most of February, the shade had been operated without additional mass in the room and temperature swings were extreme. Two days prior to the beginning of the first test period, concrete blocks were placed in the test room identical to the direct-gain room. The data are not shown for the first day because the rooms had not yet come into equilibrium. The room with the Insealshaid provides performance comparable to that of the direct-gain room, but without the intense internal lighting levels associated with unimpeded direct sun. It would seem that the decreased heat losses at night associated with the IR reflective material and the multiple glazing effect are about compensated by the increased heat losses during the day associated with absorption in the darker layer.

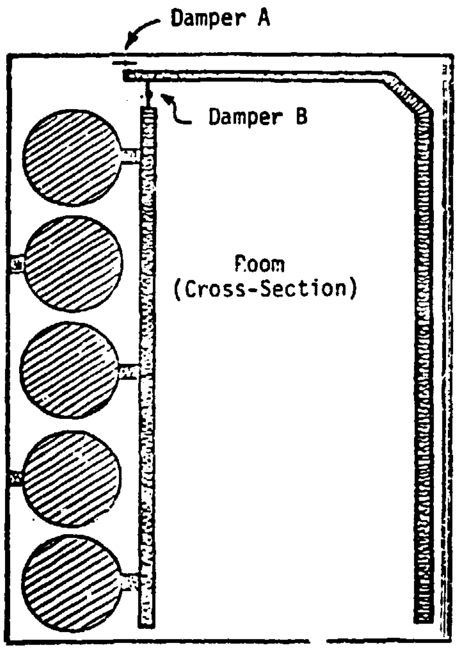


Fig. 9. A test room with an air convective loop test is shown schematically. Air rises up the collector surface which is exposed to the direct sun, flows across the top of the room through a special duct, and down through the thermal storage. The return air path is through the room at floor level. Three hundred gallons of water are contained in ten 30 gallon drums on their sides. The air passage is blocked on alternate sides of the drums causing the air to flow back and forth across the drums as it flows from the top toward the bottom. A pair of dampers are operated twice daily. Damper A, when opened, allows air to flow from the collector to the thermal storage, but when closed, prevents reverse circulation at night. Damper B, when opened, allows air flow from thermal storage into the room. The dampers were operated on the same schedule as the Beadwall; no attempt was made to control the room temperature through manipulation of Damper B. Peak temperatures observed in the air stream exiting the collector on sunny days were observed to be 180°. Minimum and maximum temperatures on February 24 were observed to be as follows for the ten water drums.

Drum	Minimum Temperature °F	Maximum Temperature °F
1 (Top)	96	107
3 (Mid)	75	81
5 (Bottom)	62	66

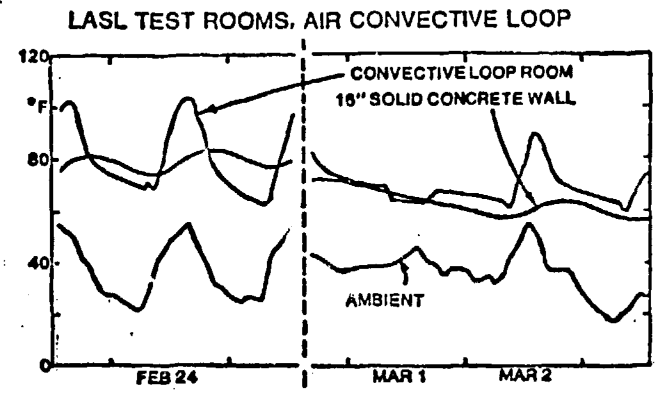


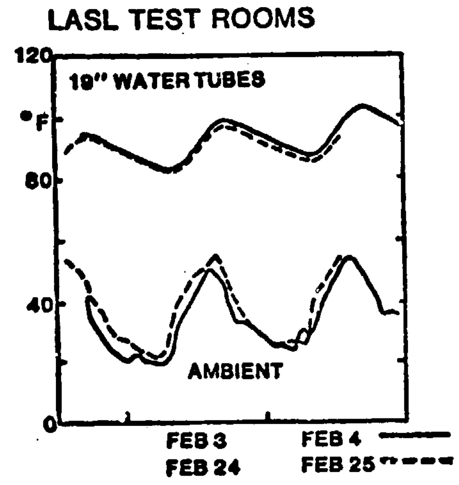
Fig. 10. Convective Loop. Data taken on the convective loop test room are shown. This room has not functioned especially well and we believe the temperature swing in the room could be reduced by making some design modifications. Changes which should be considered are the following:

1. **Provide a return air path from heat storage to the collector inlet which does not pass through the room.**

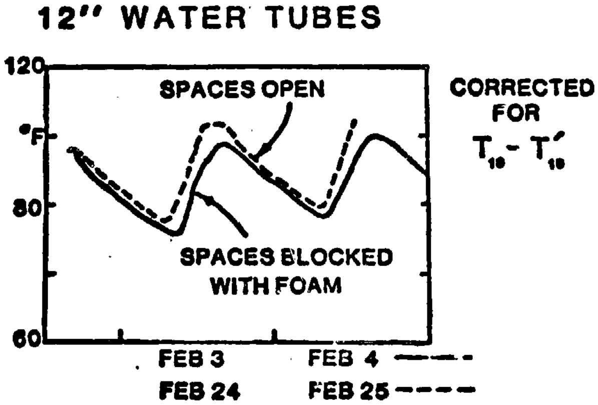
2. **Increase the efficiency of the collector by providing increased heat transfer surface to the air. A mesh surface, such as has been successfully used in many air collectors should be considered.**

3. Provide more heat transfer surface from the air to the thermal storage. This could be done by storing the water in smaller containers.

Fig. 11. Effect of styrofoam blocking strips in the water wall rooms. Since LASL has only one test room for each of the two sizes of water wall tubes, it was not possible to obtain a direct side-by-side comparison with and without the styrofoam blocks between the tubes. The next best way to make a comparison is to observe operation with the blocks in place for a few days and then with the blocks removed for an additional few days. Since the weather is not precisely the same an interpretation of the data may be somewhat confused. One way of making a comparison is to use another test room as a reference. Such a comparison is shown in this figure. Two nearly identical clear-day sequences were observed on February 3 and 4 and subsequently on February 24 and 25. Both sequences were during essentially cloudless sunny days. A comparison of ambient temperatures and of the 19 in. water tube room is shown in part (a). The 19 in. tubes had the styrofoam blocks in place during both sequences. The weather conditions are almost the same and the response of the test room is the same within about 30°F. Part (b) of the figure shows the comparison



11(a)



11(b)

of the room with the 12 in. water tubes. During February 3-4 the room was operated with the spaces blocked. However during the second, February 26 and 27 period, the blocks had been removed allowing the sun to shine through directly into the room. Some peaking of the temperature at midday can be observed.

The temperatures for the second time period were adjusted slightly by sutracting the observed temperature difference between the two test periods measured in the 19 in. water wall room. This should provide a first-order correction to the data accounting for the slight difference between the weather during the two time periods. In any case this adjustment is small and is less than the observed difference with and without the blocks. The performance is clearly better without the blocks than with the blocks. There are two factors which might account for a difference. First, the styrofoam blocks are light in color and will reflect some sun out of the room that would otherwise enter the room. Second, the blocks prevent air from flowing from the room to the glass surface. This should have the effect of reducing heat losses at night but also increasing heat losses during the day. In any case, it would appear that the blocks have an adverse effect on performance.

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In addition to the globe temperature measurements which have been shown here, there are 5 to 10 additional measurements made in each test room in order to better understand the performance. There is not enough space in this paper to present this information but it has been studied at LASL. We are in the process of making detailed mathematical models for each room in order to validate these models against the observed performance of the rooms.

References:

1. J. D. Balcomb, R. D. McFarland and S. W. Moore, "Simulation Analysis of Passive Solar Heated Buildings--Comparison with Test Room Results," presented at the International Solar Energy Society, American Section Annual Meeting, June, 1977.

2. Report and Communication, March 8, 1978, Suntek to S. W. Moore.